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LEONARD W. WING, EDITOR

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EDITORIAL

RHYTHM STATISTICS

IF some notable or not so notable of some centuries ago were dropped by a time machine onto a Twentieth Century scene, he surely would not recognize statistics of today. To him in his day, statistics would have meant only a count or listing of things in the state. Probably the statistics would have been for use of practicing politicians, but surely not for scientists. We can feel certain, however, that our ancient one would not recognize the vast group of concepts now called *statistics*.

In its simplest form, statistics only tabulates information. A machine recording the number of cars passing across a line on the highway records tabulatable information. The United States census counts people and things. These seemingly simple enumerations are most complex operations in actual practice.

Yet statistics as a *discipline* goes far, far beyond counting. It seeks to determine order or lack of order in recorded information. The application of statistics in science may be said chiefly to be this: tests of order or lack of order.

Tests of order have been developed around nonrhythmic or static situations. If one wishes to test the preference of a chicken for one of two different foods the experimental set up for gathering the statistical information might be very simple. The bird is given two choices. An observer watches the bird, or has a recording instrument watch for him, and records how many times the chicken chooses the respective foods. Then one tests for preference with respect to chance. If the chicken shows no preference, and presuming the conditions of choice and opportunities to exercise it were equal, the number of pecks at each food will be equal (or the difference in number of pecks "not statistically significant").

The respective choices of the bird in this experiment are independent of each other. The tenth choice of food is independent of the ninth choice. And the eleventh choice is a new one independent of the tenth. The fact that the bird prefers one food over the other does not make the tenth choice depend upon the ninth or the eleventh. It is likened to the flip of a coin; each flip is a new operation not related to previous or succeeding operations. (Of course we could set up an experiment such that one food might make another desirable. Thus, a spoonful of chili might make water very desirable.)

But in cycle analysis, we are faced with a different set of conditions and situations. Events or a natural time series are not independent of each other. The number of birds in the woods today is not a new operation but one dependent upon the number last year (along with a host of other factors, of course). The temperature of the air today is not a new thing independent of that occurring yesterday. The gauge height of Lake Michigan this morning is not independent of the gauge height of yesterday, or last week, or last year. The reasons are substantially the same in all natural time series. The events continue from one time to another; they are not spontaneously generated like the flip of a coin or the peck of the chicken at a feeder. This dependence of events upon each other gives "serial correlation" in varying degrees to a time series. All natural time series seem to have this characteristic.

In a time series having cycles, we still have another complication not yet amenable to satisfactory testing. Cycles have *rhythm*, *timing*, and *length* (as well as *amplitude*). There are no usable mathematical tests of rhythm significance. Because of this, there is also no test of significance of timing and length. The reasons go back to the fundamentals of statistics. They have been developed for testing non-rhythmic situations, the bird's choice of foods, for example.

One of the really crying needs of cycle research right now is a mathematical test for rhythm significance. Undoubtedly such tests could and will be developed when someone with the time, interest, aptitude, and mathematical background undertakes the task. He would need a lot of persistence also. But it would be one of the ten-strikes of cycle research.

At some future time, therefore, it may be possible to apply a formula to a time series with visible rhythm, like that of the Lynx with its strong 9.6-year cycle, and thereby to measure the series significance of apparent and visible rhythm. The 9.6 shows strongly in the Lynx. But in the tree rings, 9.6 has low amplitude. Hence, testing for rhythm significance of a cycle with low amplitude where rhythm may be invisible is clearly another task from that of testing a visible rhythm.

This need of mathematical tests of rhythm, both visible and invisible kinds, is just about the most important gap in our cycle analytical methods. When that gap is filled, we should be able to run a formula through a time series (or a time series through a formula) and say that a rhythm of such and such characteristics is or is not "statistically significant."

ERRATA, VOL. 3 NO. 3

Page 58, line 5, read *4.220* Page 58, line 9, read *0.002* Page 65, Table 2, read *4.22*
Page 74. Figure 12, read *4.222-cycle, temperature lows.*

THE FORECAST OF DROUGHT

by A. STREIFF. M.Am.Soc.C.E.
New York City

PERIODIC recurrences of natural phenomena has been a subject of scientific inquiry for a long time. Dr. C. F. Marvin stated (1): "The primary obligation of the Weather Bureau is to forecast the weather, and the principle of cycles might be used in this work if the cyclical recurrences are real and the effects are important. Real cycles of very small amplitude would have very little forecasting value." The multi-annual cycles in rainfall, temperature and pressure are generally submerged by the amplitudes of daily weather changes, and have no value for the daily weather service.

The periodic variations of rainfall have been extensively studied by Hellmann (2), Brueckner (3), Jenkin (4), Moore (5), Brooks (6), Abbé Gabriel (7), Schokalsky (8), Hann (9), Stockman (10), Henry (11), Tannehill (12), and a great many others. They have been discussed by Huntington and Visher (13), Elisée Reclus (14), and a great many other authors on physical geography and climatology. All of these tend to verify the above statement with reference to the daily forecasts of the National Weather Service, which have attained a high state of perfection without the aid of cycles.

Importance of Drought Forecast

Forecasting a coming drought is an urgent problem of universal importance. Thirty-five years ago the near-failure of a large investment in a newly built hydro-electric station, due to an unexpected drought of long duration, precipitated a new search with special reference to hydraulic engineering problems. As compared with weather service, an important difference fortunately existed. For this application, no day-to-day accuracy is needed. The possibility to forecast the coming of flood or drought years would be a great advance. In addition, an approximate quantitative estimate would be helpful. That greatly simplified the problem as compared with the exacting demands of Weather Service, though even then the outlook was doubtful.

Climate through the ages has been subject to many oscillations, as shown by the researches of Heer (15), Fritz (16), Neumayer (17), Brooks (18), Brueckner (19), Hobbs (20), Clements (21), to name a few of the many investigators. In spite of the vast amount of existing literature, nothing to permit forecasting the approach of a drought had come to light.

At last the search yielded an unexpected and important clue.

The work of Professor Edward Brueckner: "Klimaschwankungen seit 1700," which was published in 1890, furnished a suggestion for a possible solution. In discussing the effect of the climatic cycle in Chapter IX of his work, Brueckner emphasized that the practical importance of the cycle--which, he claimed, is traceable through geological into modern times--is chiefly evident in all those phenomena which are of primary interest in hydraulic engineering. Brueckner finds important secular changes in glaciers, lakes and swamps, the number of floods, channel depth for interior navigation, groundwater and sanitation, agriculture in semi-arid regions. Excepting the choice of mean meteorological values, no mention is made of any importance of the climatic cycle for the science of meteorology.

This automatically led to the question: "If a climatic cycle really exists which causes such sweeping changes, why is not the cycle equally prominent in the records of thermometer, barometer and raingage?"

The answer is to be found in a basic difference in hydrographic and meteorological data. Weather service deals with MOMENTARY values; with POINT observations in space and time. The task of hydraulic engineering is the control and conservation of water; hence it deals only with CUMULATIVE values. Rainfall is integrated over longitude, latitude and time, and partially runs off; the run-off is again integrated in lakes and storage basins.

By this multiple integrating process the shorter cyclic periods disappear, while the longer cyclic periods tend to remain. Suppose a curve of rainfall data contains 3 cycles having periods of a length of 1, 1/2 and 1/3; the period of the long cycle taken equal to 1. These cycles are supposed to be superimposed upon each other. The ordinates could be represented by

$$Y = \sin\alpha + \sin 2\alpha + \sin 3\alpha$$

This, integrated four times, and omitting the series of the constants, which add an exponential series only, would become

$$Y = \sin\alpha + 1/16 \sin 2\alpha + 1/81 \sin 3\alpha$$

It may be seen at once that the shorter cycles have been reduced by the integrations to 1/16 and 1/81 of their original amplitudes and have in comparison with the long-period cycle practically disappeared.

In meteorological data the short-period cycles predominate, while in hydraulic data the long-period cycles are more prominent. Lakes exhibit long-sustained periods of rise and fall, while abrupt daily weather changes apparently continue with no important change in overall weather.

Method of Analysis

The most widely used system is that of "moving averages," called by Brueckner "Lustren Mittel" from the word "lustrum," a space of five years. Brueckner employed exclusively series of five-year averages. While these disclose cycles, they fail to separate them. A discussion of the known methods of more detailed analysis and a suitable method for application on hydraulic data, was published in 1926 (22). C. F. Marvin, in a footnote, commented as follows:

"G. G. Stokes, in Proceedings of the Royal Society of London, vol. 29, 1879, pp. 122-123 pointed out the possibilities of an integration method in arriving at the solution of trigonometric functions, but his conception appears to have been essentially that of trial periods, afterwards more fully developed by Shuster. Otherwise, apparently, there is no earlier application than the one outlined herein to the problem of hidden periodicities."

The solution referred to had been suggested by earlier publications by Chrystal (23), Vercelli (24), and Lagrange (25). Additional details were published in 1928 (26).

The components thus obtained are not pure harmonics, but groups of more complex composition, sufficiently far removed in length of period from the next group to be distinctly separable. They serve the purpose of extrapolation very well, permitting also quantitative estimates of value, if used in conjunction with further correlations.

The latter refer to existing cycles in nature which are known to repeat themselves; the source of which resides in the sun (33). These are the periodic recurrences of solar activity, expressed by the so-called Wolf number. Unfortunately, unlike the annual cycle, the Wolf cycle is variable. Nevertheless, the variability is not excessive, and not enough to impair the usefulness of the correlation.

If the Wolf number series is analyzed, the correlation of the components with terrestrial phenomena becomes easily visible. (22), (29). Taking Wolf cycle as the unit, the always recurring components are those of 2, 1, 1/2, and 1/4 length of period. According to their original investigators, they are called the BRUECKNER-HALE, the HORTON (31), and the Clough (32) cycle, which vary in length in unison with the Wolf cycle.

Existence of the correlation is not generally accepted. This, it is believed, is due wholly to the following two causes:

(1) The general use of the method of "moving averages" already referred to. The meteorologist A. Berget stated (28): "The meteorologists, statisticians above all, have invariably sought to compile general averages in the superposition of which the periodicities disappear." A more detailed analysis is needed. If the series are not resolved into their components, correlations are not clearly defined.

(2) The view prevails that such a correlation would have to be simultaneous and equal all over the globe. This, however, is not the case; droughts occur in one region while floods devastate another.

Why should an equal effect be expected to take place at the same time everywhere?

The force of gravity is as universal as the radiations from the sun. Yet the tides vary enormously with a small change in geographical location. The amplitude varies as much as from 50 to 2 feet with a few hundred miles from the bay of Fundy to Nantucket. They vary greatly in phase all over the world. Tidal scientists now believe that the ocean basins have their own period of oscillation determined by their length and depth. The complicated effects are caused by the topographical features, the sizes and shapes and the contour map of the bottom of the seas, bays, gulfs and inlets.

It is further generally accepted that the overall circulation of the atmosphere is profoundly changed by the earth's motions, as are the accelerations which produce the tidal movements. The thin atmospheric film around the globe, in its continuous state of flow from high to low pressure, is greatly influenced by the contour map of the continents. It seems conceivable that cosmic forces, though simultaneously present everywhere, produce different effects in different locations, depending on whether the winds blow from hot and dry to cold and wet regions or in the opposite direction.

Fortunately it is not necessary to speculate about the mysteries of the cosmos for the intended purpose. The facts are that conclusions based on the ASSUMED existence of the correlation have actually materialized at the predicted time many years into the future. The practical application need not enter the realm of solar radiation and science. It has been found that the old index, the Wolf number, is a useful tool in charting the probability of a coming drought.

Nature of the Brueckner Cycle.

Brueckner himself regarded the varying length of the climatic cycle to be due to three cycles superimposed upon each other. Two of these are in evidence in the records of two centuries, the third one, called by Brueckner a "diluvial" cycle, has a period too long to be traceable from recorded measurements. Figure 2, page 407 of the Monthly Weather Review of October, 1929 indicates how the Brueckner cycle can be considered composed of the cycle of returning polarity of spots discovered by Professor Hale, superimposed on the longer "secular" cycle so-called, of which only two unequal periods are contained in the existing record of the Wolf numbers.

The main feature of the Brueckner cycle is the Hale component. It is traceable in every record, with an amplitude varying with geographical location. The cycle is prominently in evidence in the Southwest; it can be regarded as the time table of the "dust bowl." It is herein referred to under the name "Brueckner-Hale" cycle. The last two periods have been close to twenty years in length. Returning for the third time within the span of recorded measurements, the dustbowl appears as a cumulative effect of the low portion of the Brueckner-Hale cycle, towards the end thereof and the beginning of the new cycle.

Lacking the information furnished by 63 more years of recorded measurements when making his studies in the years preceding 1890, and armed only with his "Lustren Mittel," Brueckner quotes 36 authors on correlation with the Wolf numbers, but does not find any himself. He nevertheless firmly expresses belief in its existence, and ascribes failure of proof to the then imperfect state of technique of measurement of solar radiation, since then so vastly improved by Abbot (27).

In the year 1929 it was decided to submit the above theory to an actual test. This was probably the first "practical application" of the results of the vast amount of research by the erudite and ingenious author of "Climatic changes since 1700," which was published 63 years ago.

The "application" was made as follows:

Since 1890 there have been three complete periods of the Brueckner-Hale cycle. These are superimposed on the rising portion of the Secular cycle, which apparently is passing its crest. In the year 1929 the Buchanan dam on the Colorado River in Texas was promoted as a private hydro-electric power enterprise. A report was then made on the possibilities of future power output, from which report the chart, Figure 1, is taken. The flow record was available up to 1929 and is shown on the chart. The Brueckner-Hale cycle is shown superimposed on the Secular cycle. The course of the cycle in the past was taken from the same chart which furnished Fig. 3, page 408, Monthly Weather Review, October 1929. A continuation beyond 1929 is extrapolated in a dotted line.

Many years later, in 1948, two additional dams were built on the same river, and the preparatory study of the flow record furnished Figure 2. On this chart the average annual discharges are shown as single points, connected by straight lines, drawn up to the scale shown at the left of the graph. The Brueckner-Hale cycle was obtained according to the method published in 1926.

On the forecast made in 1929, a scale of discharges in cubic feet per second has been attached to the right hand side of the graph.

Comparing the forecast with the actual record, it may be seen that the Brueckner-Hale cycle indeed did culminate around 1937 as had been shown on the 1929 chart, and that the mean flow actually had risen for eight years as predicted on the basis of the recurring cycle. The chart shows the maximum value of the Brueckner-Hale cycle to have been 4360 cubic feet per second, whereas the forecast, made eight years before, was 3900 cubic feet per second. The forecast was 10 1/2 per cent too low, while the mean flow in 1937 was 100% higher than the mean flow in 1929, eight years before, when the forecast was made.

Isaiah Bowman, in a discourse on "Our expanding and contracting desert." states: "Finally, we do not know whether we are in an ascending or descending phase of a long-range change in climate." That problem is nearing solution, and with increasing length of records the occurrence of the next severe drought in the Southwest can even now be anticipated. The drought conditions are generally simultaneous across Texas, as shown by R. Lowry (30), in spite of the fact that the normal rainfall varies from 10 to 50 inches from East to West. Over greater distances the phase varies geographical location.

Beyond eight years the numerical values of forecast and record diverge more and more, although still showing a measure of qualitative agreement. For practical purposes, eight years may be considered sufficient.

Intermediate Droughts.

It may be noted from Fig. 2 that "intermediate" droughts occur. High flow years alternate with low ones in an apparently fortuitous succession. From an analysis of the records of a certain region, a "flow pattern" emerges. In this pattern the shorter cycles named above are superimposed upon each other.

In a former publication (34) a number of examples containing qualitative and quantitative forecasts were made. These were published several years ahead of occurrence. They can, therefore, be compared today with the actual record at any time. These forecasts pertain to the Great Lakes region. The Horton cycle is the predominant feature, as in many other regions. It was noted by E. D. Archibald in records from Northern India already in 1900. Other plains regions show the same features. The minima in the Great Lakes region of North America and in the great plains of Russia strikingly agree as to time of occurrence. These minima took place in both regions in the years 1909-1910; 1913-1914; 1919-1920; 1924-1925. By means of the correlation with the Wolf numbers, these minima are easily anticipated numerically as well, several years in advance. Without recourse to the Wolf number, it is not readily determined, because the intervals are not regular, and the extrapolation not clearly indicated.

But also in the semi-arid Southwest

similar results can be obtained. This was demonstrated on the Guadalupe River in Texas. In the year 1944 a report was made covering a refinancing procedure for three hydro-electric plants located on that stream. The chart, Fig. 3, shows the output curve for the plants in the year 1944, which was 45,490,500 Kilowatt-hours. The study disclosed that the output would drop in 1948, four years hence, to an unprecedented low of 19,400,000 kilowatt-hours. The chart, Fig. 4, shows the actual output to be 20,690,000 Kilowatt-hours; a difference of six per cent with the estimate made four years before, while the output dropped to 45.5% of the 1944 output. Drought was accurately foreseen.

It is evident that without the methods referred to above, without reference to recurring cycles, such estimates far into the future can not be made. If however, a systematic sequence is plainly evident, and can be unreveled and regrouped, the above becomes possible.

This was again confirmed quite recently. Since 1933 the Cycle has completed another full period. A terrific drought has again raged in Texas for many years. On the Lower Colorado River, prior to the fall of 1952, the last year of high flow had occurred eleven years before in 1941.

In January, 1952 the drought still reigned unabated. In a report dated January 7, 1952 to the Lower Colorado River Authority, dealing with the output of the Authority's hydro-electric system and while the reservoirs were at an all-time low, the statement is made: "Full reservoirs may be expected in 1952 and 1953." In the same year the report was written.

Indeed they were full in 1952 and all through 1953.

Brueckner stated that his work "Climatic cycles since 1700" was the result of three years of labor, and required processing of some 38,000 observations: a truly amazing performance. It should not cause surprise that thirty-five years of continuous research would show results not possible in Brueckner's time. Records covering 63 more years are now available.

Conclusions

It is concluded that there ARE systematic sequences which will permit multiannual forecasts of the occurrence of droughts. The general course of moisture in the Southwest is even now discernible. The next "intermediate" drought within the span of the Brueckner-Hale cycle can be expected to occur with the same probability as demonstrated before. The reason for the frequently expressed unpredictable fortuity of drought in spite of the vast amount of existing literature is not to be found in the lack of more data of basic causes, but in the means of analysis employed.

It is not possible to make daily forecasts on the basis of cycles. It is however quite possible to announce the year or years of drought in the Southwest a number of years in advance.

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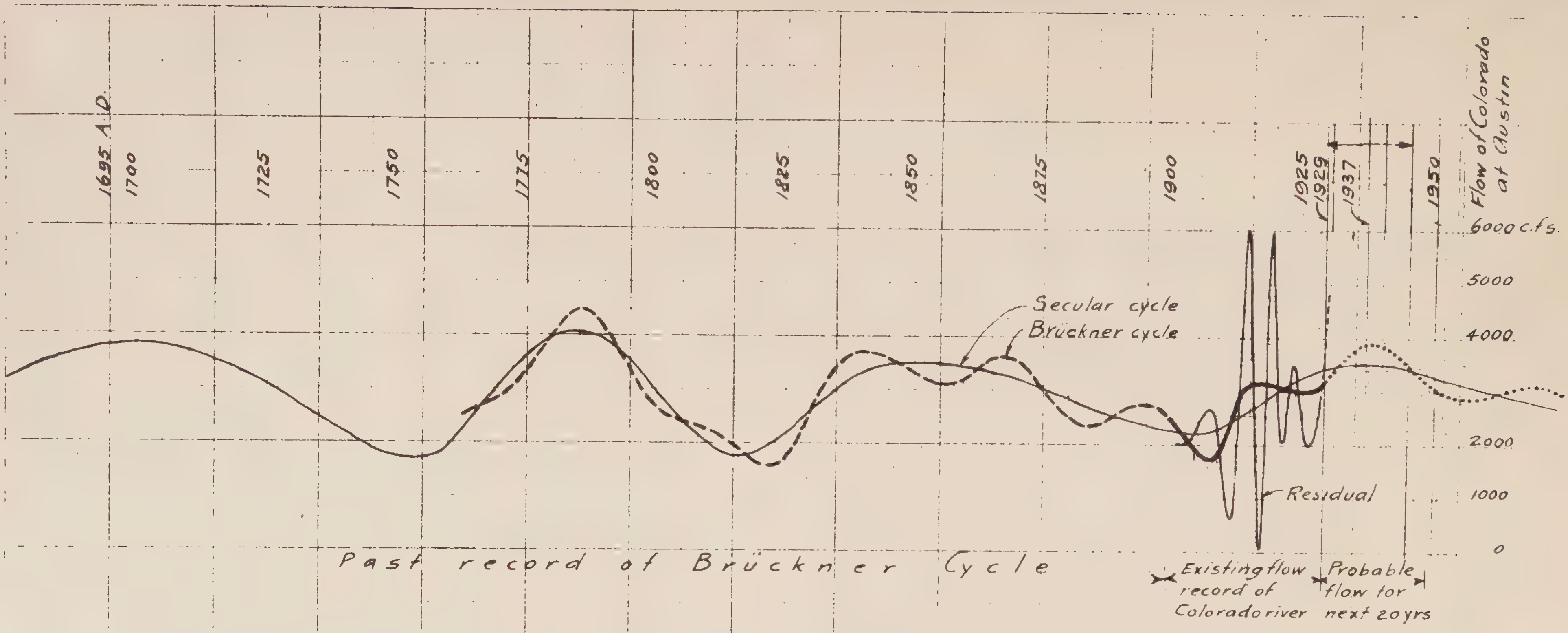
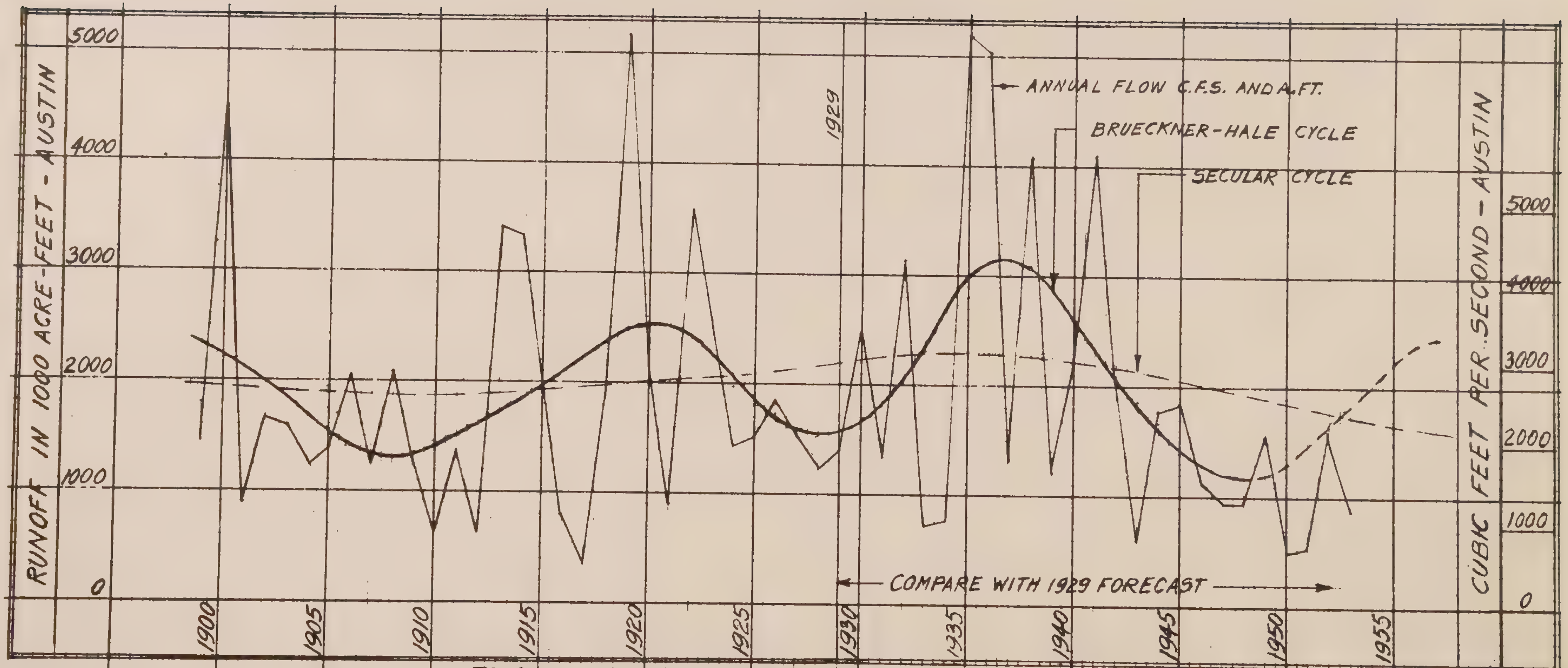


PROBABLE
PAST AND FUTURE FLOW
OF
COLORADO RIVER

FIG. 1

A. STREIFF
M. AM SOC. C.E.

FIG. A 4



FLOW OF COLORADO RIVER AT AUSTIN, TEXAS

FIG. 2

TOTAL DAILY OUTPUT OF HYDRO ELECTRIC STATIONS

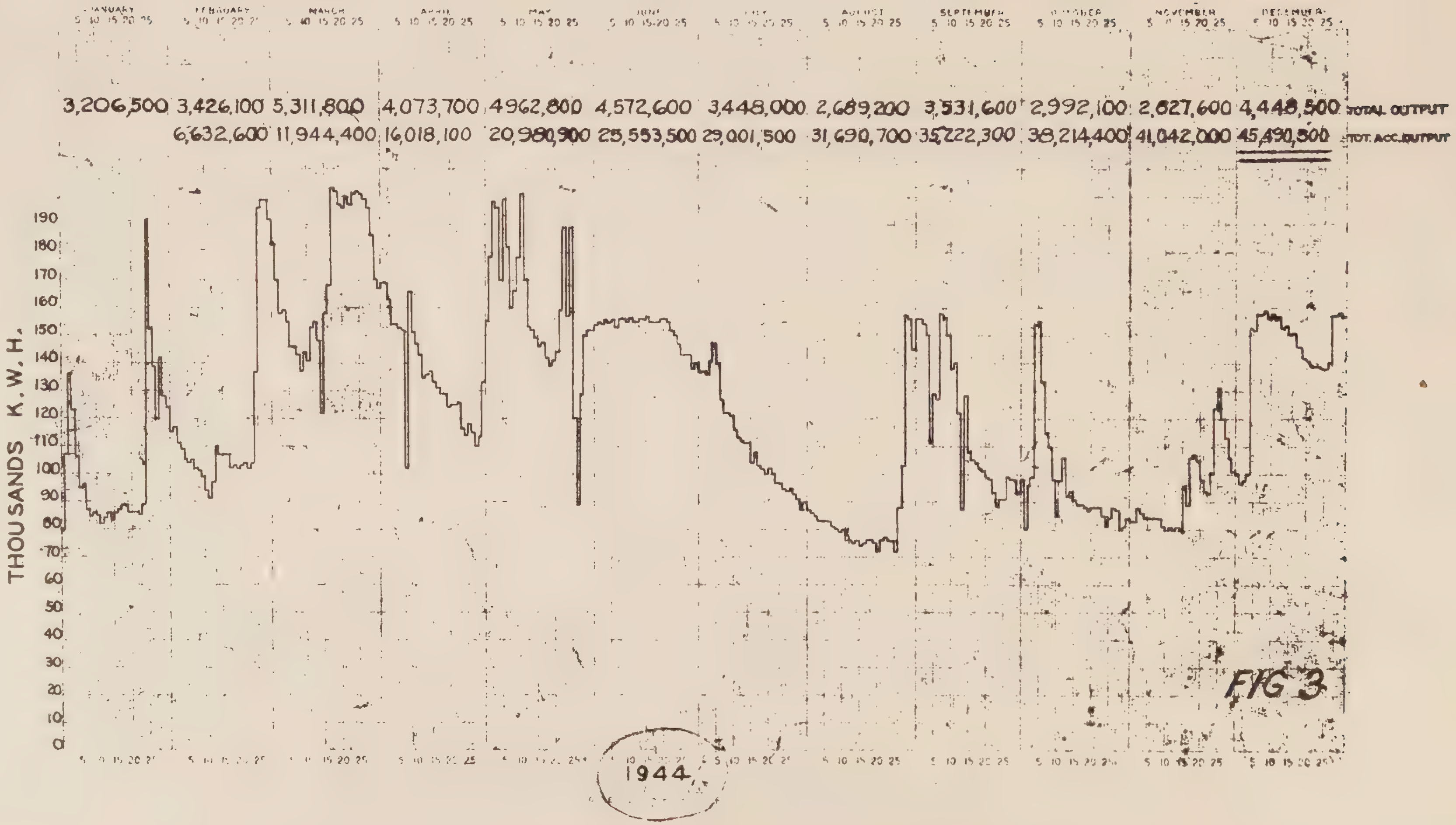


FIG 3

TOTAL DAILY OUTPUT OF HYDRO-ELECTRIC STATIONS

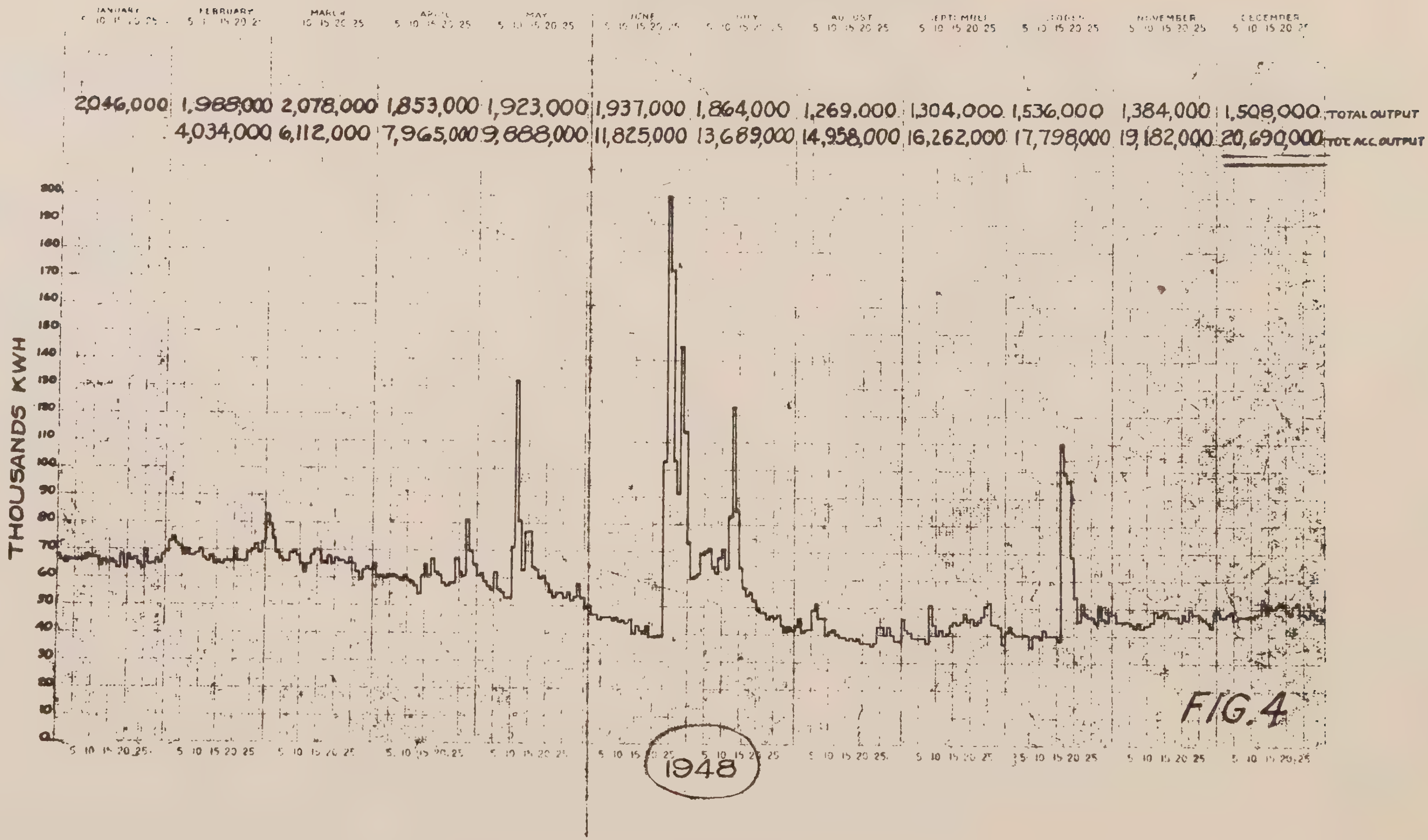


FIG. 4

THE 9.3- AND 8.6-YEAR CYCLES IN COPPER PRICES

by Edward R. Dewey, Director
Foundation for the Study of Cycles

COPPER prices, 1784-1953 act as if they had been influenced concurrently by rhythmic forces of 9.3 and 8.6 years in length.

In view of the fact that pig iron prices behave similarly,[1] the behavior of copper prices is not too surprising. Many price series go up and down more or less together. In fact, the surprising thing is that the cycles do not measure exactly the same in each series. In pig iron prices the lengths measure 9.20 and 8.53 years; in copper prices 9.28 and 8.60 years. These differences suggest that with time series so short (relative to the length of the cycle), it may not be possible, with present techniques, and with our present knowledge of cycles, to be sure of cycle lengths within perhaps 1%.

Since the discovery of the 9.2- and the 8.5-year cycles in pig iron prices some additional discoveries in regard to cycles of this general order of magnitude have been made.

G. T. Lane, in a comprehensive periodic table analysis of sunspot numbers, found evidence of cycles with lengths of 8.36, 8.76, and 9.30 years respectively.[2] Although the periodic table cannot be trusted to give exact lengths unless the length of the series equals the fundamental of which the true lengths are harmonics,[3] these findings of Lane's are provocative. It would be interesting to see if periodic table analyses of copper and pig iron prices showed two 8 + year cycles corresponding to those found on the sun.

My own work with sunspot numbers shows that if allowance is made for the distorting effect of cycles of nearby length, the cycle shown by Lane's work to be 9.3 years long is really 9.2 years long (Lane used raw data only).

It is not known whether or not there are cycles of nearby length in copper prices not present in pig iron prices which would have a similar distorting effect, i.e. which would make a 9.2-year cycle appear to be 9.3 years long.

The second piece of work referred to above having to do with cycles of this order of magnitude concerns cycles in the abundance of grasshoppers. This work shows that for the period 1840-1940 an index of grasshopper abundance in the United States has fluctuated with a rhythm or beat which is typically 9.2 or 9.3 years long.[4] (A year ago I thought 9.3 years was the correct length, but more refined measurements suggest 9.2 years as more probable.)

In spite of the correspondence in cycle length one should not be hasty about deducing a cause and effect relationship between solar disturbances and animal life on earth. There *may* be such a relationship, or both the sun and the earth *may* be subject to cosmic forces as yet unsuspected (but like the old ether, convenient to postulate), or the whole business may be merely a matter of coincidence.

There is, however, enough evidence here of non-random behavior to make a recording of the observed facts of interest and of value.

Copper prices, like all price series, are subject to a variety of forces. These forces include (a) long term growth trend, (b) inflation, (c) random events such as war, tariff changes, price control, etc., and (d) cyclic forces.

Growth Trend. For all practical purposes there is no long term trend in copper prices. Prices (in terms of gold) at the present time are lower than they were in the 1780's.

Long term growth trend is the tendency of a series of numbers to increase (or decrease) gradually over a long span of time. In the case of copper, the span of time under consideration is 170 years.

The word *trend* can also be used to denote a general upward or downward *tendency* over a short period of time.

Inflation. There have been two important periods of inflation--during and after the Civil War and since 1933. The course of inflation is not cyclic. The future course of inflation has to be estimated by the use of brains.

Random Fluctuations. Random events have been numerous in the history of copper

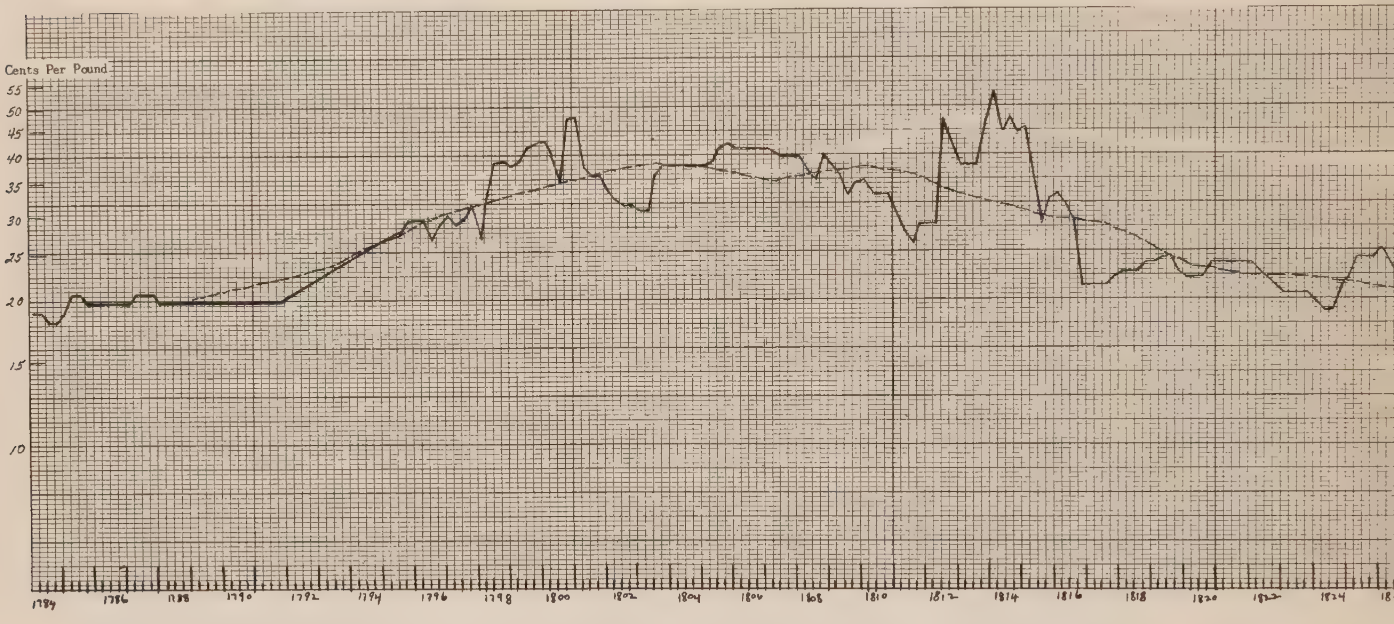


FIG. 1. COPPER PRICES, FIRST QUARTER 1784—FOURTH QUARTER 1953.
Solid line--actual prices.
Dashed line--prices adjusted to gold basis.

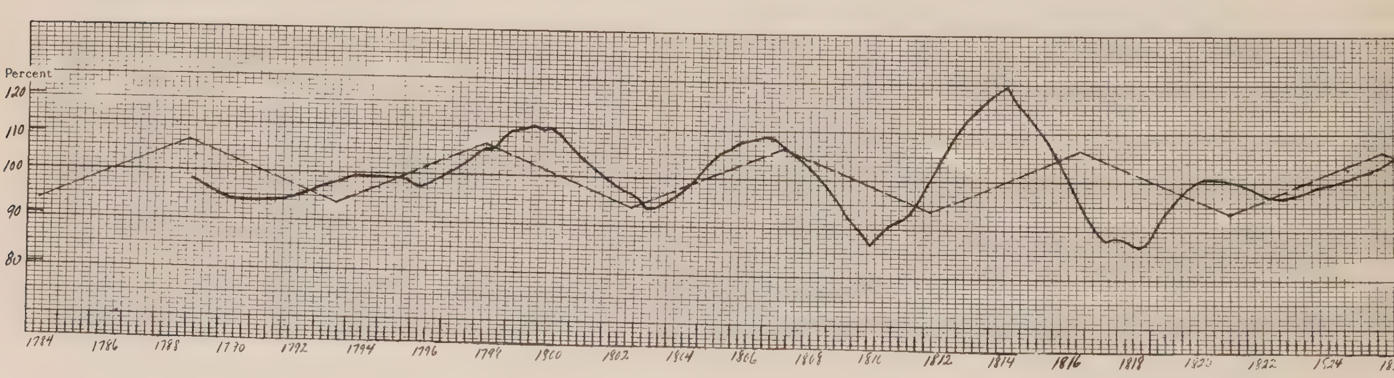


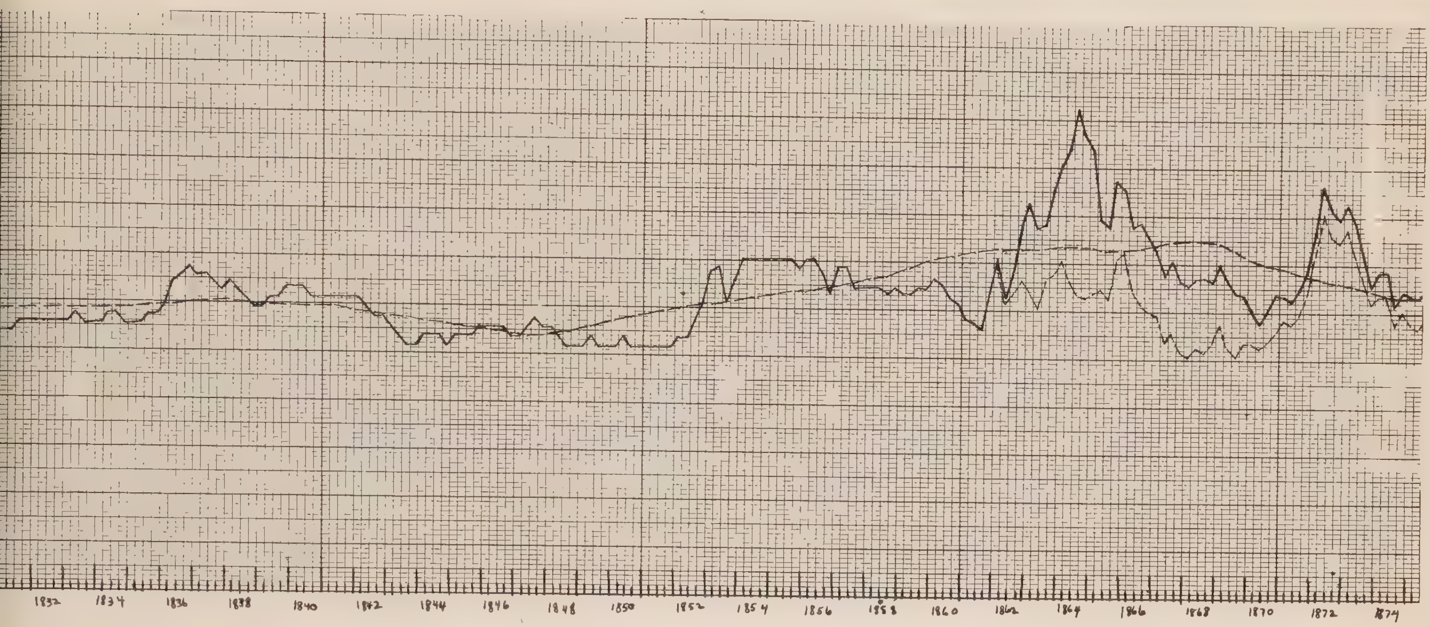
FIG. 2. THE 9.3-YEAR CYCLE IN COPPER PRICES, 1784—1953.
Actual prices smoothed by a 17-quarter moving average, expressed

prices. However many of the fluctuations which are commonly thought to be random fit into the cyclic patterns in such a way as to suggest that they are at least partially the result of cyclic forces.

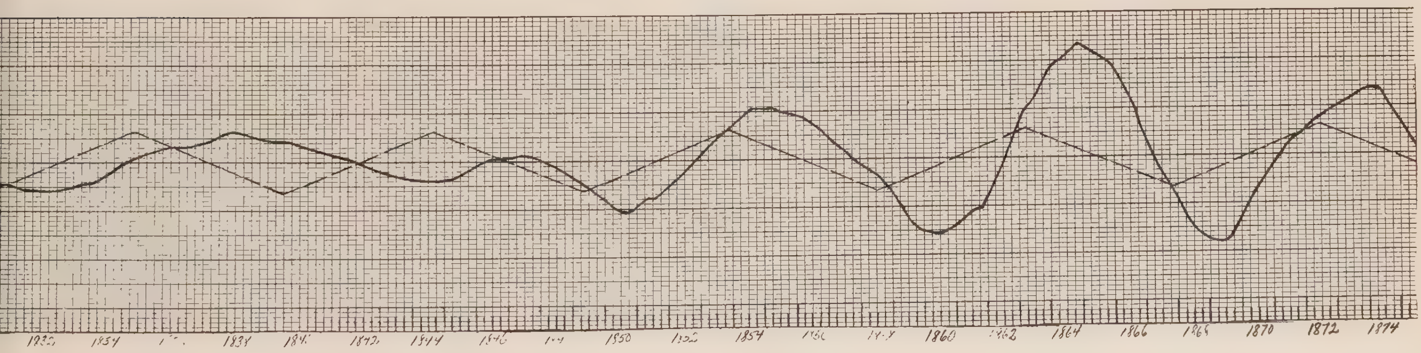
Cycles. In addition to trend, inflation, and random forces, copper prices act as if they had been subject to a number of cyclic forces—some long term, some short term.

We are privileged to postulate possible cyclic forces when we have cyclic behavior, such as the 18 repetitions of the 9.3- and 8.6-year cycles, about to be discussed. As many repetitions as this, of the regularity evidenced, cannot easily be the result of chance.

A multiple harmonic analysis of pig iron prices suggested the possibility of at least 36 important cycles over 4 years in



Smooth broken line—short term trend (41 quarter (10 1/4-year) centered moving average). Ratio scale.



as percentages of their own 41-quarter (10 1/4-year) moving average. The broken line diagrams the 9.3-year cycle, Ratio scale.

length in that series of figures.5

No similar study of copper prices has ever been made but there is no reason to think that there would be fewer cycles in copper prices than in pig iron prices. These other cycles, if present, constitute a considerable distorting element.

The Data

Copper prices are shown by quarters, in currency and in gold, in Fig. 1 on pages 100—103 inc. In Fig. 1 there is also shown the short term trend of these prices.

The 9.3-Year Cycle

If we now smooth the prices shown in Fig. 1 and express these smoothed values as percentages above or below the short term trend just referred to, we get the

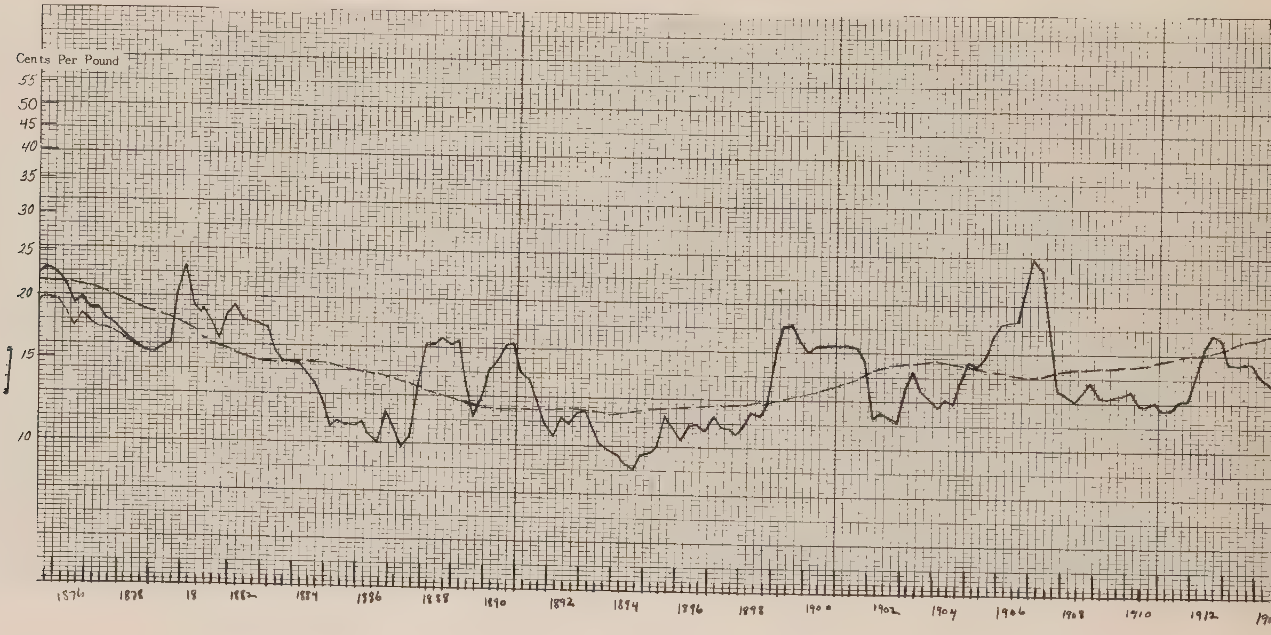


FIG. 1. CONTINUED

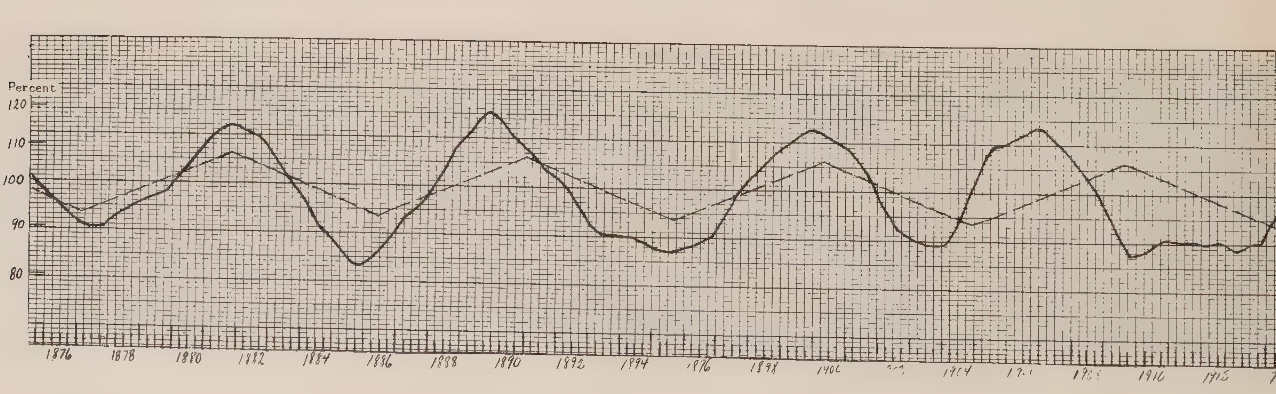


FIG. 2. CONTINUED

values shown in Fig. 2 on the same pages.

(The technician may wish to know that the trend used is a 41-quarter (10 1/4-year) geometric moving average; the smoothing was effected by means of a 17-quarter (4 1/4-year) geometric moving average.)

Such a manipulation minimizes the longer and shorter cycles more than it does cycles of medium length, such as those in the general neighborhood of 8, 9, or 10 years long.

Even casual inspection shows a cycle, slightly over 9 years in length, present throughout the entire history of 170 years. Study of the figures indicates that this cycle has the following characteristics:

The length, as nearly as I have been able to measure it, is 9.28 years from crest to crest or trough to trough. Crests

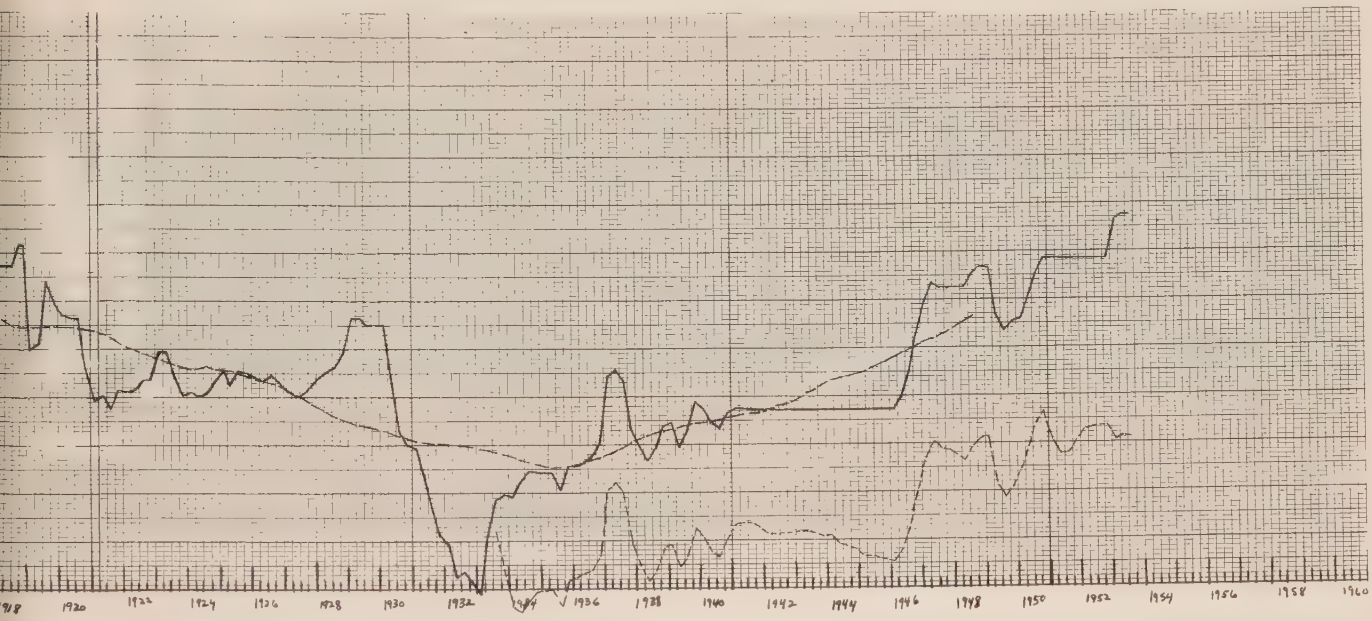


FIG. 1. CONTINUED

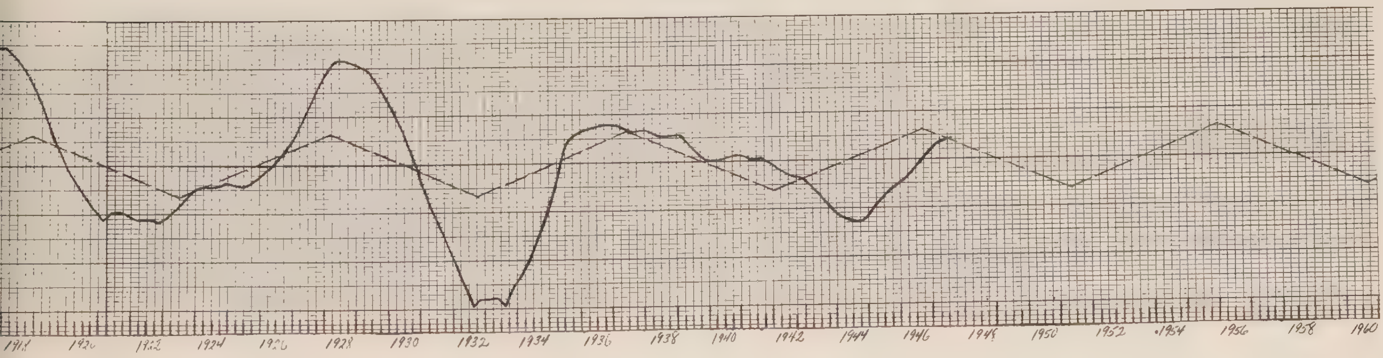


FIG. 2. CONTINUED

fall at the beginning of the first quarter of 1789 and every 9.28 years thereafter. Troughs fall 4.64 years after crests. The ideal time for the latest trough was May 1951, for the next crest, January 1, 1956.

Typical amplitude of the ideal 9.28-year cycle in the actual prices is 114.3% at time of crest, 87.5% at time of trough. The shape, as nearly as we have been able to determine it, is zig-zag when the original data are plotted on ratio scale, but of course in the smoothed figures the tops and bottoms are rounded over. The 9.28-year cycle is diagrammed in Fig. 2 by means of a broken line.

The 8.6-Year Cycle

If we now adjust the figures in Fig. 2 for the effect of a perfectly regular 9.28-year periodicity of the characteris-

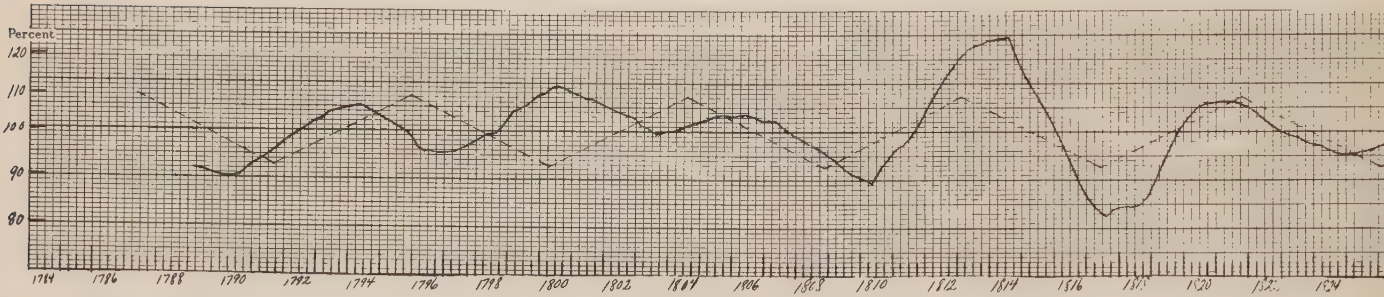


FIG. 3. THE 8.6-YEAR CYCLE IN COPPER PRICES, 1784—1953.
The percentages shown in Fig. 2 adjusted for a perfectly regular 9.3-year cycle.

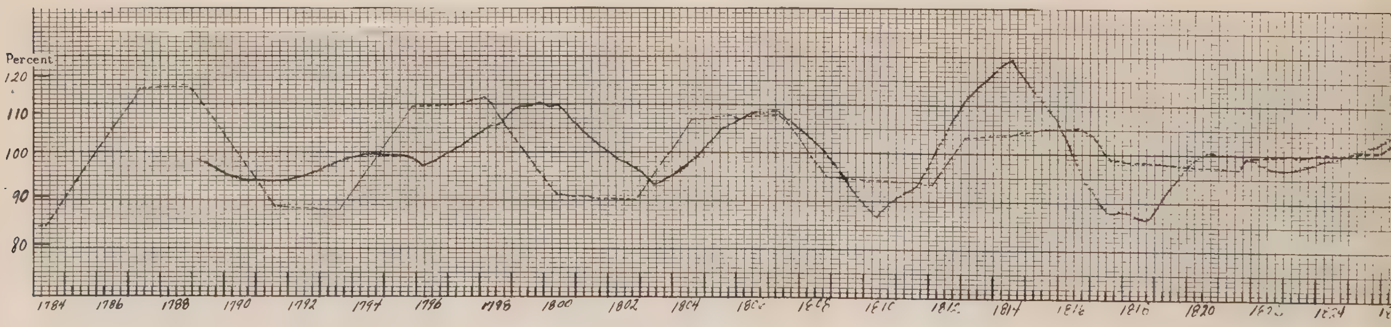


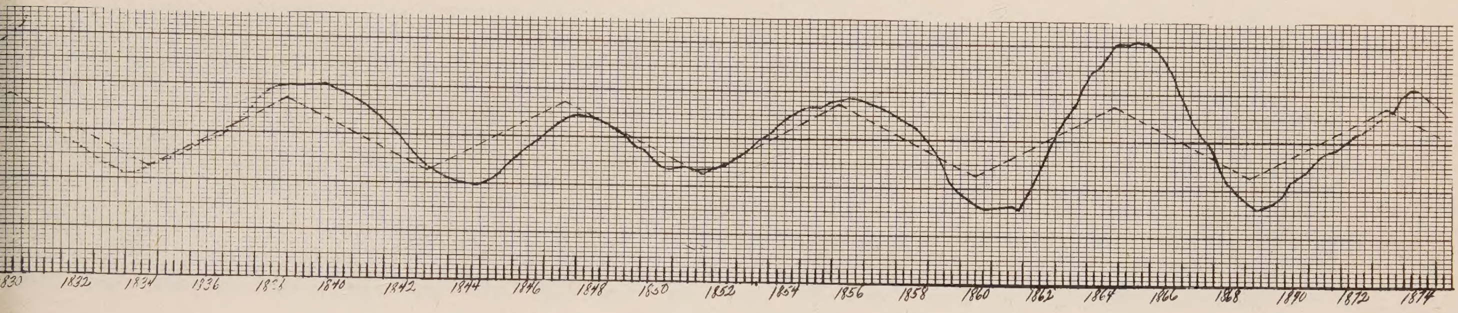
FIG. 4. A COMPOSITE OF THE 9.3- AND THE 8.6-YEAR CYCLES IN COPPER PRICES, 1784—1953.
The solid line on this chart is the same as the solid line in Fig. 2 namely, actual

tics indicated we get the curve shown in Fig. 3. An 8½-year cycle is clearly evident by simple inspection. It proves to have the following characteristics:

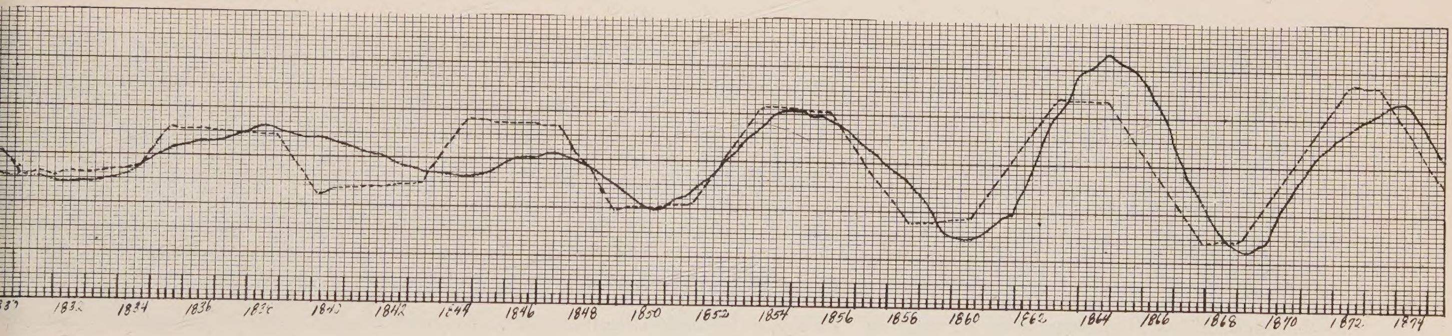
Length, 8.6 years from crest to crest (or trough to trough). Crests fall at the first quarter of 1783 and every 8.6 years thereafter. Troughs fall 4.3 years after crests. The ideal time for the next crest is therefore February, 1955.

Typical amplitude of the 8.6-year cycle in actual prices was 111.9% of trend at time of crest, 89.3% of trend at time of trough. The shape, like that of the 9.28-year cycle, seems to be zig-zag (on ratio scale) in the original figures.

Fig. 4 shows the values of Fig. 2 in comparison with a syntheses of the 8.6- and 9.28-year cycles. There is no question but that the correspondence is better.



Broken line shows a diagram of a perfectly regular 8.60-year cycle. Ratio scale.



prices smoothed by a 17-quarter moving average expressed as percentages of their 41-quarter (10 1/4-year) moving average.
The broken line diagrams the composite of the 9.3 and 8.6-year cycles. Ratio scale.

Variable Length and Amplitude

It is clear that the manifest cycle--the cycle that you see--is one of varying length and varying amplitude. Is this behavior the result of a single cyclic force with these characteristics? Or is it the result of the interplay of two cyclic forces of rigid length and strength, as suggested by the foregoing exposition.

That is, is the concept of two interacting cycles of 8.6 and 9.3 years in length merely descriptive of a varying cycle? Or does it throw some light upon cause--are there really two cyclic forces of the indicated wave length?

In the present state of our knowledge of cycles no one knows. However it is well worth trying to find out about.

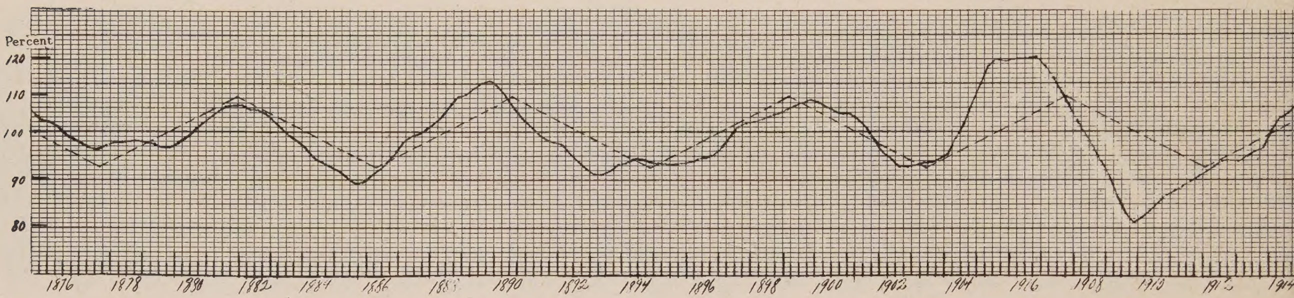


FIG. 3 CONTINUED

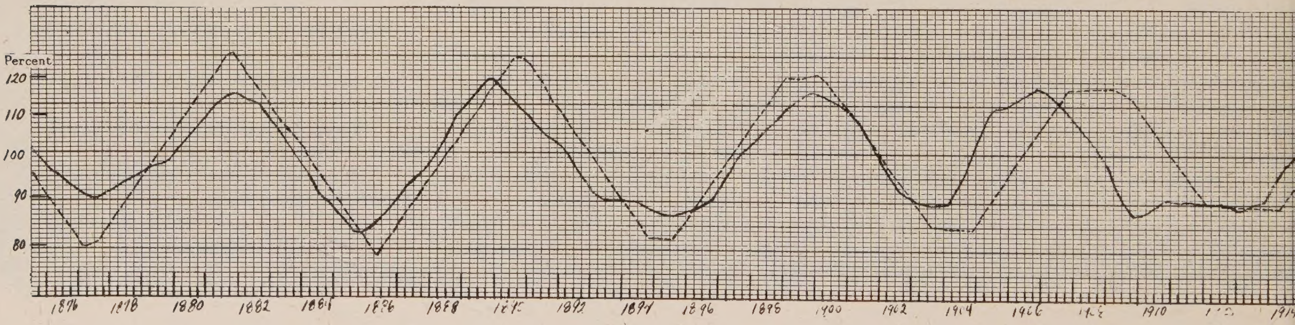


FIG. 4. CONTINUED

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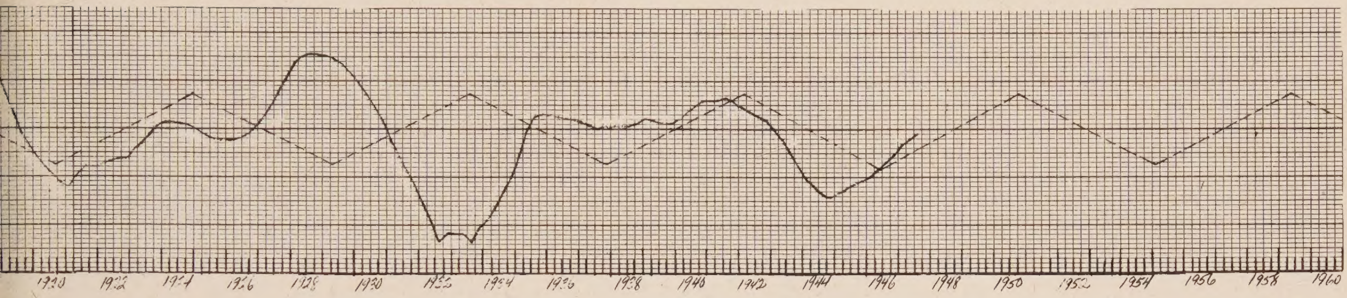

FIG. 3. CONTINUED

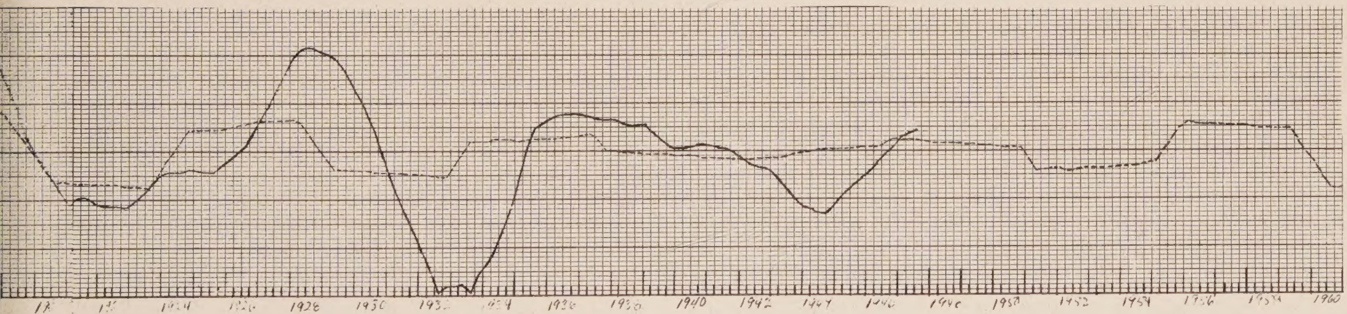

FIG. 4. CONTINUED